Adaptive browsing: sensitivity to time pressure and task difficulty

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Abstract

Two experiments explored how learners allocate limited time across a set of relevant on-line texts, in order to determine the extent to which time allocation is sensitive to local task demands. The first experiment supported the idea that learners will spend more of their time reading easier texts when reading-time is more limited; the second experiment showed that readers shift preference towards harder texts when their learning goals are more demanding. These phenomena evince an impressive capability of readers. Further, the experiments reveal that the most common method of time allocation is a version of satisficing (Reader and Payne, 2007) in which preference for texts emerges without any explicit comparison of the texts (the longest time spent reading each text is on the first time that text is encountered). These experiments therefore offer further empirical confirmation for a method of time allocation that relies on monitoring on-line texts as they are read, and which is sensitive to learning goals, available time and text difficulty.

Keywords: browsing, information foraging, satisficing, sampling

1 Introduction

1.1 Information Foraging

George Miller's description of humans as informavores (Miller, 1983) carries with it the assumption that we make sensible choices about which information to consume. Until comparatively recently choice of information sources was seldom studied, but the popularity of the World Wide Web has led to an increased need to understand what decisions people make and what factors affect the decision making process. On-line texts are nowadays so abundant that the major problem for readers is no longer finding any relevant document, but rather allocating their limited time across the profusion of relevant sources. Similarly, information providers must concern themselves with how to attract and keep the attention of readers who will genuinely benefit. For both these reasons, we regard it as a very important research goal to understand how users allocate time across relevant texts, and what aspects of the texts and the reading tasks they are sensitive to.

Information foraging theory (Pirolli & Card, 1999; Sandstrom, 1994) has been proposed as a theoretical framework for understanding on-line information choice and time allocation. Information foraging draws heavily on optimal foraging theory (OFT) which was originally developed to understand the foraging decisions made by animals (see Stephens & Krebs, 1986). OFT sees animals as acting to maximize the rate of gain of some currency such as energy intake, and makes the guiding assumption that they are optimal in doing this. The optimality assumption has proven to be one of the more controversial claims of OFT (see, e.g. Pierce and Ollason, 1987) but in reality it is no different from what many researchers have been doing for generations. Simply, OFT doesn't make the *claim* that people or other organisms are optimal, rather, optimality is an *assumption* that serves as a normative or idealized model. Any deviations from the optimum can by explored experimentally and, depending on the results, the model revised in its detail or replaced. Only if none of the available models fit the optimality assumption might we be justified in abandoning it.

Based on this approach, Pirolli and Card (1999) have argued that information seeking behavior can be understood by assuming that people seek to maximize the rate of gain of valuable information. Value is a multidimensional construct influenced

by factors such as relevance, difficulty level and reliability - critically, the value of information is assumed to vary as a function of the embedding task, the task for which the information is being sought. Maximizing the rate of gain of information value also entails a consideration of the costs of information search - especially the time taken to find and process that information (technically known in the OFT literature as search time and handling time respectively). With respect to information choice, cost might also contain some measure of cognitive effort such as ease of processing, with people perhaps preferring texts that require less mental effort, although in many cases this will correlate with time.

The idea that value of information varies with the embedding task is central to the very construct of relevance, so perhaps it is not surprising that much of the work on information foraging theory (IFT) has, one way or another, concerned the relevance of information sources and how this is judged and used by information seekers. In particular the concept of information scent - the judgement of the relevance of distal source from local cues such as link labels - has driven most of the IFT-based empirical and technological research in HCI (Card et al, 2001, Fu & Pirolli, 2007, Olston & Chi, 2003).

In this article, following Reader and Payne (2002; 2007) we study preferences among relevant documents that differ in difficulty. We make an a priori argument that such preferences should depend on the time available to the reader and on the complexity of the embedding task (the task for which information is being sought). We test whether human information foraging is adaptive by testing whether it favours the information sources that one might expect from a priori arguments. Further, we explore the browsing strategies that are used to allow such preferences to be affected.

1.2 Difficulty-level of documents

Expository documents can be too easy or too difficult for learners. When the task is to learn as much as possible by reading a document then, as shown by Wolfe, Schreiner, Rehder, Laham, Foltz, Kintsch, and Landauer (1998), the reader will learn more when the information in the text overlaps to a moderate extent with the reader's initial knowledge. When there is a great deal of overlap, there is little new information to learn, but when the information is overwhelmingly new it will be too difficult to

assimilate (these authors further show how to predict the appropriate difficulty-level for a reader, using latent semantic analysis).

Reader and Payne (2007), allowed participants limited time to browse freely among four texts on the human heart (the same texts as studied by Wolfe et al, 1998), with the goal of writing a brief essay after the browsing period. Browsing behaviour was shown to be adaptive in the sense that participants with greater knowledge spent more time reading more difficult texts (or, equivalently given the study design, less time reading easier texts). This finding is consistent with the assumption of IFT that browsers should maximise rate of gain of valuable information. But additionally, superimposed on any effect of individual differences, aspects of readers' embedding task are likely to shift the optimal difficulty level of documents. Information foragers' sensitivity to such aspects is a more demanding test of IFT's assumption.

We explore two such aspects: the time available to the reader, and the complexity of the task for which information is being sought. First, consider the time available to the reader. We argue that limiting the time available should shift attention toward easier sources. Assuming texts are neither so easy that they offer no new information (or opportunity to reactivate existing knowledge), nor so hard as to be completely incomprehensible, then we might expect hard texts to require more 'handling time' - more time to understand and memorise. When time is limited, a reader must somehow judge whether they have sufficient time to assimilate the information they encounter: under this view a harder text represents a gamble with higher potential gain, but higher risk that the time will be insufficient to realise this gain. Thus, the attractiveness of a harder text should diminish when there is less time available.

There is already some empirical evidence relevant to this argument. First, in the study referred to above (Reader & Payne, 2007), although preferences (as measured by time spent on each text) differed in the predicted direction according to participants' expertise, overall participants preferred easier texts than was predicted to be optimal for them by a computer-based educational text selection program based on Latent Semantic Analysis (Landauer, Foltz & Laham, 1998).

One possibility is that this was exactly the adaptive response to time pressure that we would predict. However, and contrary to this argument, participants in Reader and Payne’s Experiment 1 who were given 15 minutes to study the texts showed more preference for the easiest text than did those who were given 7 minutes. We were

inclined to explain away this contradictory finding by noting that 7-minutes was simply too short a time, given the quantity of text on view, to allow deliberate preferences in time allocation to emerge, and indeed we found weaker effects of expertise in the 7-minute condition. Nevertheless, this inconsistent finding surely suggests a need for further empirical research.

Further support for our hypothesis that time-pressure will prompt preference for easier source materials can be found in the related literature on study time allocation, which investigates time allocation among discrete items of varying difficulty during study for a memory test. It must be noted that the empirical paradigm in this literature is quite distinct from browsing multiple texts, in that it usually uses much simpler materials than expository texts (e.g., words or word-pairs), and in that it warns participants that items vary in difficulty as well as typically marking each item with a notional difficulty level or else allowing participants an initial judgment phase in which they assess the difficulty of items.

The modal finding from this literature is that participants generally spend more time on more difficult items. For example, Son and Metcalfe (2000) evaluated 19 published studies and found that 35 out of the 46 treatment conditions participants allocated the majority of their time to more difficult items. However, in the majority of these studies participants were allowed unlimited time to complete the task. In subsequent studies where participants were placed under time pressure they typically allocated the majority of their time to the easier items (Metcalfe, 2002, Metcalfe & Kornell, 2005; Thiede & Dunlosky, 1999). This can be interpreted as participants attempting to maximise the number of items remembered per unit time. If the items are of equal value (as they are in a straightforward memory test) then it is sensible to spend time on the quicker, easier items.

Accordingly, our first experimental prediction is that information foragers will exhibit a preference for easier expository texts when time pressure is increased, and they will be able to express this preference despite being initially unaware of the difficulty level of the available texts.

The second aspect of the reader's situation that we study is the complexity of the embedding task. We argue that when readers are preparing for a more difficult test their preferences will shift toward more difficult sources. This prediction seems intuitively clear, but is interesting precisely because it taps the construct of information value that is critical to IFT. If foragers were merely trying to maximise

uptake of information, then the complexity of the embedding task should not affect preference among relevant sources, which should depend, as we have argued, on the reader's expertise and on available time. But consider the reader who is preparing for a test that is known to be difficult. Now the parameters of the gamble we mentioned earlier are shifted in favour of risk-taking. There is little point in studying an easier text just because one is confident of having enough time to process and remember its content. Instead, one should gamble on being able to cope with a text which contains information at the appropriate level for the test. (For clarity, we should note that although we have framed this prediction as an effect of preparing for more difficult questions, we could just as well have framed it the other way round: preparing for easier questions will shift preference toward easier texts. There is no ready, meaningful neutral point, so the hypothesis relates only to relative difficulty of test questions and texts.)

1.3 Strategies for time allocation among multiple texts

Our final concern in this article is the strategies that information foragers might adopt in order to preferentially allocate attention among relevant texts. If readers can successfully adjust their preferences among relevant texts, how is this accomplished?

Reader and Payne (2007) identified two plausible strategies for allocating time preferentially across a set of texts. The first, ‘sampling’, involves a prior stage of judgment and comparison – briefly inspecting each text so as to choose one or some for further study. The second strategy for time allocation does not separate judgment of texts from studying them. Rather, when using a ‘satisficing’ strategy, readers will set a threshold of acceptability (presumably in terms of some currency like rate of information value gain), and continue to read a text until this threshold is no longer met. Crucially, satisificing involves no explicit comparison of texts. Rather, each text is opened in turn and time spent reading depends on ongoing monitoring of the experience.

We use the term 'satisficing' for the monitor-reject strategy because its operation is so close to the original formulation of satisficing by Simon (1956), albeit extended from a singular decision (whether to accept an offer on a house) to an ongoing, moment-by-moment decision (whether to continue to read a text). In the

literature since Simon, satisficing is often used to denote any behaviour that seeks 'good enough' rather than optimal solutions. This broader usage is found in the information seeking literature, too. For example in the work of Warwick, Rimmer, Blandford, Gow & Buchanan (2009) information seekers are described as satisficing because they persist with tried and tested general methods in the face of more efficient alternatives. This observation has very strong echoes of early work on 'acquired mediocrity' in the use of interactive systems like word processors (eg., Rosson, 1983).

Our use of satisficing denotes a very particular strategy as described above, although, it must be admitted the definition leaves aspects unspecified, such as how the acceptability threshold is set before reading and monitored during reading, and what patch-size of unit of text is being judged (see Duggan & Payne, 2009 for a detailed consideration of these issues in the context of skim-reading a single document).

Our definition of 'sampling' bears an interesting relation to the important body of work on 'document triage', which is the process by which documents are rapidly judged for relevance (e.g., Buchanan & Lozides, 2007; Buchanan & Owen, 2008; Cockburn, Savage & Wallace, 2005). These investigations, like ours, begin with the observation that readers of electronic texts often have to negotiate a surfeit of riches; and therefore need to somehow allocate attention according to the relevance of electronic texts for their current purposes. However, this work does not make empirical distinctions between strategies like sampling and satisficing, but rather assumes that rapid judgments of relevance are part of the process (on the basis of diary and survey studies – e.g. Adler, Gujar, Harrison, O'Hara & Sellen, 1998; Liu, 2005).

Sampling and satisficing are strategies that can result in the adaptive allocation of attention among multiple texts and evidence suggests that people can use one or other strategy depending on external factors. For example sampling may be more effective when one can make relatively rapid and reliable judgements of text quality. In support of this, Reader and Payne (2007) found that while satisficing was the dominant strategy when time-pressured readers were requested to learn from a set of texts (Reader and Payne, 2007, Experiment 1) the provision of brief summaries of textual content led to sampling becoming the majority strategy (Experiment 2).

It is not yet clear what other factors may affect strategy choice. Therefore in addition to exploring the effects of time pressure and task difficulty on preferences for

text difficulty (see above) the two experiments reported below examine the effect of differential time pressure and number of texts (4 versus 8 texts) on strategy selection. Further in these new experiments participants are presented with a study goal which is arguably more demanding; a multiple-choice test instead of a brief essay. It is possible that the lack of specificity of a brief essay as a study goal contributed to the popularity of the satisficing strategy as well as the preference for easy texts in Reader and Payne (2007). In Experiment 1, participants are given a demanding pre-test and asked to study for a similar test with different questions.

2 Experiment 1

2.1 Method

2.1.1 Participants.

Sixty-four participants took part, 16 per condition. Most participants were psychology undergraduates who received course credit for their participation. The others were undergraduates from other university departments, who were paid for their participation. Fifteen were male and forty-nine female (mean age 20.2, range 19 to 24). Participants were assigned to experimental conditions according to their order of arrival at the laboratory.

2.1.2 Design.

A between-participants design was used to evaluate the effect of time constraints on the participants' reading strategies and time allocation. Additionally we manipulated the number of texts available to read - participants were provided with either four or eight texts to study; however, with respect to time allocation it was necessary to analyse these two conditions separately so that number of texts was treated as a test of the generality of the primary effects. Participants were given either 15 minutes (more time-pressure) or between 30 and 45 minutes (less time-pressure) to study the texts. The less time-pressure condition was set up such that participants were required to read for the first 30 minutes and when they reached this time they could either proceed to the test or continue reading for up to a further 15 minutes, after which time they were forced to proceed to the test. The minimum time of 30 minutes for this condition was chosen as approximately the time it would take to read 4 × 1,600 word texts at the average reading speed of 250 words per minute (it was

also twice the time given to those in the more time-pressure condition). The additional time served to further reduce time pressure by allowing readers discretion about when exactly to stop reading. On average these participants read for 31.2 minutes (SD = 2.7 minutes) showing that most participants decided to quit. The main dependent variable was the time spent on each of the texts.

2.1.3 Materials.

The study used eight texts on the topic of the human heart and circulatory system. The texts used in the four-text condition were those used by Wolfe et al. (1998) and also Reader and Payne (2007). The length of the texts ranged from 1,533 to 1,672 words and they varied in level of difficulty. Text A was taken from a children's book (Silverstein & Silverstein, 1983), Text B was an introductory text for adult readers (Davis & Park 1981), Text C was written for undergraduate anatomy students (Basmajian, 1982), and Text D was taken from a medical school book (Gould, 1953). The additional four texts used in the eight-text condition were taken from a variety of sources and the difficulty level was matched as closely as possible to each of the four original texts. In order of increasing difficulty the texts were: Text E – (Burnie, 1995); Text F – (*Texas Heart Institute*); Text G – (Mohrman, 2003); Text H – (Bahr & Johnston, 1992). Difficulty level was matched using the Intelligent Essay Assessor from the LSA website. It compared each text with the existing four texts on the same topic that are stored in its database and produced cosine values for the similarity between the text input and the four original stored texts. Therefore, the four additional texts were designed such that the similarity cosines between them and the four original texts were as high as we could achieve. Text E and Text A had a similarity cosine value of .89, Text F and Text B had a cosine value of .86, Text G and Text C had a cosine value of .79, and Text H and Text D had a cosine value of .82. All the texts were four pages long and ranged from 1275 to 1672 words in length.

The texts were accessed via a menu system at the left of the screen which was visible throughout the reading phase, and allowed participants to access any page of any text at any time. This ensured that readers could choose freely which parts of the texts they studied. The menu consisted of four buttons for each text, which were headed with the text author (for example, 'Silverstein' or 'Gould') and labelled with the page number one to four. There was no other information given about the texts. Therefore, readers were unable to use the menu to discriminate between texts

according to their difficulty, relevance, or length. The text on each page was presented as a single paragraph of text with single line spacing. The font used was MS Sans Serif, regular style, Western script, size 10. The average line length was 100 characters. There was an indication at the bottom of the screen detailing how many minutes they had been reading so that participants could keep track of how long they had been reading and how much time remained.

The order in which the texts were presented in the menu (i.e., from top to bottom) varied for each participant. Twenty-four different orders were used for the four-text condition, and thirty-two for the eight-text condition (this meant that each participant in the eight-text condition was presented with a different text order). The orders for the four-text condition were derived using all possible orders (24 in total) and using eight of these twice. The eight combinations which were used twice were produced by selecting two at random from each of the combinations with text number 1, 2, 3, and 4 in the first position. Consequently, although order was not completely counterbalanced in the four-text conditions, each text appeared in the first position four times (twice in each time-pressure condition). For the eight text condition, the text orders were randomly generated, and then selected to ensure that each text appeared in first position on four occasions each. As participants clicked on the text pages, the software recorded the time. There was no facility on the screen to inform participants which pages had been viewed, only which page was currently being viewed.

An on-screen short answer test about the heart was given to the participants before and after the reading phase. Questions appeared on the screen and participants were required to type the answers below each question. The test consisted of 17 questions relating to the structure and function of the human heart. This test was taken from the Wolfe et al. (1998) study, and also used in Reader and Payne (2007). The 17 questions were split over two pages, and once participants had finished the first screen page and moved onto the next, they were unable to return. This was to avoid participants finding the answers to the earlier questions in the later questions. Within each page participants were free to answer the questions in any order. The maximum score for the test was 40. The test was the one used in the study by Wolfe at al. (1998). Two example questions appear below.

Question 1. How many types of blood vessels are there? Please name them.

Answer. *5 types - capillaries, arteries, veins, arterioles and veinules.*
Mark. *6 points - 1 for number of types, 3 for the names (6 if also get arterioles and veinules)*

Question 5. What is the protein which makes quick oxygen/carbon-dioxide transfer possible? How many molecules of oxygen can each such protein carry?
Answer. *Haemoglobin. Each protein can carry 4 molecules of oxygen.*
Mark. *2 points, 1 for haemoglobin, 1 for 4 molecules.*

2.1.4 Procedure

Having completed a personal information questionnaire, participants were asked to write a 250 word essay on the anatomy, function and purpose of the human heart. There was no time limit for this, but participants were required to write within 10 words of the word limit before they were able to proceed to the next stage of the experiment. This restriction was imposed to enable easier analysis of the essays after the experiment, using the Intelligent Essay Assessor. To help participants to keep track of how many words had been written, a word count was displayed on the right of the screen which had to show a number between 241 and 259 in order for the proceed button to be enabled[1].

If participants' knowledge of the heart was very limited and they were unable to write 250 words, the set up of the experiment made it possible for them to write anything just to make up the number of words. However, all essays were read through by the experimenter after the experiment to ensure that this had not occurred. Once completed, the pre-test was presented on screen and participants were required to type the answers in the spaces provided.

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[1] Studies show that when essay length is less constrained, essay word count is more strongly related to knowledge (Rehder, 1998). The question of how long an essay needs to be in order to provide an accurate estimation of the participants' knowledge was investigated by Rehder et al (1998), who examined essays from participants in the Wolfe et al study. They looked at how effective LSA was as a measure in predicting the relation between the pre-questionnaire score with the number of words in the participant's essay. It was discovered that the first 60 words of an essay are non predictive, and between 70 and 200 words was increasingly predictive, but with decreasing marginal returns. Based on this analysis, a word count of 250 words was chosen for our study.

Once the test had been completed the participants were presented with the menu for the text reading phase. They were informed that they had either 15 minutes or between 30 and 45 minutes (subsequently referred to as *more time pressure* and *less time pressure*) to study either 4 or 8 texts, depending on condition. Participants were told to read with a view to answering more questions similar but not identical to the ones they had already answered in the pre-test. They were also told how much material there was from which they could study (number of texts, number of pages, and number of words), and how much time they could study for. They were given no information about the nature of the texts other than their topic. Special care was taken to emphasize that participants should allocate their time as they preferred and there was no requirement to read all of the texts. They were not advised that they would be required to write a second essay. Participants were not allowed to take notes while reading.

In the more time pressure condition, once the 15 minutes had passed the screen went blank and participants were asked to proceed to the next stage. In the less time pressure condition, the 'proceed to next stage' button was enabled after 30 minutes had passed, but participants could still access the texts until 45 minutes had passed, when the screen went blank. Participants were then asked to write another essay of 250 words. The same rules applied as in the pre-reading phase essay. Once they had completed the second essay they were presented with the original test and asked to complete it. Again, the same rules applied as for the pre-reading phase test.

2.2 Results and discussion

Data from three participants had to be excluded from analysis as they failed to follow the instructions properly: one participant in the four-text more time pressure condition, one in the four-text, less time pressure condition, and one in the eight-text, less time pressure condition. One participant was randomly chosen and eliminated from the eight-text, more time pressure condition so that there were fifteen participants in each experimental group.

2.2.1 Pretest scores.

The statistics for the pretest score were as follows (maximum score 40) Eight-text more time pressure condition: $M = 12.7$, $SD = 8.4$; eight-text, less time pressure condition: $M = 8.5$. $SD = 8.5$; four-text more time pressure condition: $M = 11.8$, $SD =$

8.1; four-text less time pressure condition: M = 12.0, SD = 8.5. There were no significant differences among these scores F (1,3) = .76, p = .52.

2.2.2 Browsing behaviour.

Following Reader and Payne (2007) we inspected the browsing protocols for evidence of particular strategies, as defined in Section 1.3. Participants were identified as sampling if they inspected all available texts in the first third of their available time. In the eight-text condition we additionally considered that participants may sample over an arbitrary subset of the texts – so for comparison across conditions, we considered that participants were "four-text sampling" if they inspected any four texts in the first third of their allotted time. Participants were alternatively identified as satisficing if their longest visit to each text was the first visit to that text. These strategies are by no means exhaustive (i.e., there are many possible browsing protocols that would not count as examples of either strategy) so if the residual category of particpants who are neither sampling nor satisficing is relatively small we can be confident that we are understanding particpants' browsing behaviour to a meaningful degree.

Analysis of the participants' browsing behaviour showed that there were 76.7% satisficers, 6.7% samplers, and 16.7% residuals across the four experimental conditions. The breakdown of browsing strategy for each condition is shown in Table 1.

Strategy	Condition			
	4 MT	4LT	8 MT	8LT
Satisficers	10	12	12	12
Samplers	2	1	1	0
Residuals	3	2	2	3

Table 1: Breakdown of Browsing Strategy for each condition, 4 or 8 texts, more time pressure (MT) or less time pressure (LT)

This shows a significantly higher number of participants adopted a satisficing strategy than a sampling strategy across conditions (all $p \leq 0.02$). Neither increasing

the number of texts nor removing the time limit changed the dominant browsing strategies.

A more detailed analysis was carried out on the ten participants who were classed as residuals. There were five participants in the four text condition who were classed as residuals, and three of these satisficed with three texts, and two satisficed with two texts. That is, the first visit to three/two texts was the longest visit ever made to those texts but for the other texts the re-visits were longer than the initial first visits. There were five participants in the eight text condition classed as residuals, and three of these satisficed with six texts, one satisficed with seven texts, and one who did not satisfice at all and whose behaviour appeared relatively random. Overall, although these participants were classed as residuals, they did seem to be displaying a satisficing type of behaviour, and certainly could not be considered to be using any kind of sampling, since their pattern of browsing indicated that they satisficed with most of the texts they viewed.

2.2.3 Preference for easier versus harder texts, four text conditions

An analysis was carried out to examine the proportion of time spent in the easiest and the hardest texts (texts A and D respectively) to ascertain whether available time had any effect on the amount of study time allocated to these texts (see Table 2). By considering only these two texts, we avoid the problem that times on the whole set of texts are not independent in the time-limited condition - a similar argument underpins our analysis strategy throughout the article. The hypothesis was that the proportion of time spent on Text A relative to Text D should be higher in the more time pressure condition, because time pressure leads one to favour easier texts. On this basis, it is predicted that an interaction effect will occur. A one-way analysis of variance revealed no effect of time pressure ($F[1,56]=1.37$, $p=.25$), but a main effect of text ($F[1,54)=30.63$, $p<.001$) and, importantly, a significant interaction between text and time pressure ($F[1,56]=8.3$, $p<.005$).

	Condition	
	More time pressure	Less time pressure
Easy Text (A)	39.79 (18.18)	26.09 (13.86)
Hard Text (D)	11.33 (9.34)	17.11 (8.75)

Table 2: Four-Text Conditions*:* Percentage of time spent on the easy text, A, and the hard text, D for more time pressure and less time pressure.

2.2.4 Preference for easier versus harder texts, eight-text conditions

As with the four-text condition, an analysis was carried out to examine the proportion of time participants spent on the easy texts and the hard texts. Because there were two easy texts and two hard texts in the eight-text condition, the analysis was based on the mean of the two easy and the two hard texts for each condition, more time pressure and less time pressure. Again, the prediction was that participants would spend proportionally more time on the easy texts than the hard texts in the more time pressure condition, based on the idea that time pressure results in readers spending more time on the easier texts. Table 3 shows the mean proportion of time spent in the easy and the hard texts for the eight-text condition.

		Condition	
Difficulty		More time pressure	Less time pressure
Easy	Text A	16.77 (16.93)	11.68 (10.85)
	Text E	15.15 (12.50)	6.38 (8.59)
	Mean (A+E)	*15.96 (14.65)*	*9.03 (9.98)*
Hard	Text D	8.41 (11.13)	15.80 (13.37)
	Text H	11.85 (13.54)	16.24 (21.74)
	Mean (D+H)	*10.13 (12.31)*	*16.02 (17.73)*

Table 3 Eight-Text Conditions*:* Percentage of time spent on the easy texts, A and E, and the hard texts, D and H for more time pressure and less time pressure.

Inspection of the data in Table 3 suggests that more time was spent on the easy text when participants were under greater time pressure. There were no significant differences between the time spent on the Texts A & E (the easy texts) in either the more time pressure or less time pressure condition ($t(28)=.30$, $p=.77$ and $t(28)=1.48$, $p=.45$ respectively). A similar result was found for Texts D & H (the hard texts, $t(28)=0.76$, $p=.45$, $t(28)=1.5$, $p=.15$ respectively) the times for the two easy and the two hard texts were therefore averaged as in Table 3. A 2 (Text, combined-easy v.

combined-hard) x 2 (less time pressure v. more time pressure) ANOVA revealed no main effect of text difficulty ($F(1,58) = 0.05$, $p = 0.82$), and no main effect of time pressure ($F(1,58) = 0.043$, $p = 0.84$), but a significant interaction between text difficulty and time pressure ($F(1,58) = 6.07$, $p < .05$). Analyses of simple main effects revealed that for the easy text, more time was spent reading it in the more time pressure condition than in the less time pressure condition ($F(1,58) = 4.59$, $p < .05$). For the hard texts, no difference was found between the more time pressure and less time pressure conditions ($F(1,58) = 2.24$, $p = 0.14$).

2.2.5 Satisficers and first visits to texts only

Having shown that readers spend more time reading the easier text when there is less time available to read, and that the majority of participants use a satisficing strategy, it is tempting to conclude that satisficing, with no explicit comparision of texts, is nevertheless an adaptive strategy. Nevertheless, it remains logically possible that the allocation biases we have observed are not due to satisficing per se, but to the few participants who sample, together with the residual time allocated to texts during second and subsequent visits. Consequently, to gain confidence that satisficing per se allows adaptive preference for difficulty to emerge, we repeated the main analyses, considering *only* those participants classed as satificers, and using the times participants spent on the *first* visit to each text, ignoring any subsequent visits.

2.2.5.1 Four text condition

As previously, the hypothesis was that the time spent on first visits to Easy Text A relative to Hard Text D should be higher in the more time pressure condition, because time pressure leads one to favour easier texts. A one-way analysis of variance revealed no main effect of time pressure ($F[1,44]=2.41$, $p=.13$), but a main effect of text ($F[1,44)=28.59$, $p<.001$) and, importantly, a significant interaction between text and time pressure ($F[1,44]=10.23$, $p < .005$).

	Condition	
	More time pressure	Less time pressure
Easy Text (A)	40.40 (16.83)	23.01 (14.13)
Hard Text (D)	9.11 (8.44)	15.14 (9.54)

Table 4: Four-text condition: Percentage of time spent on easy text and hard text for more time pressure and less time pressure for satisficers and first visits only

2.2.5.2 Eight-text condition

As in the four text condition, the prediction was that participants would spend more time on their first visits to easy texts than hard texts in the more time pressure condition, based on the idea that time pressure results in readers spending more time on the easier texts. Table 5 shows the mean proportion of time spent in the easy and the hard texts for the eight-text condition.

	Condition	
	More time pressure	Less time pressure
Easy Texts (A,E)	29.73 (23.45)	16.96 (10.10)
Hard Texts (D,H)	16.87 (12.86)	25.76 (13.85)

Table 5: Eight-text condition: Percentage of time spent on easy texts and hard texts for more time pressure and less time pressure for satisficers and first visits only

A 2 (Texts, easy v. hard) x 2 (less time pressure v. more time pressure) ANOVA revealed no main effect of text difficulty ($F(1,50) = 0.22$, $p = 0.64$), and no main effect of time pressure ($F(1,50) = 0.20$, $p = 0.66$), but a significant interaction between text difficulty and time pressure ($F(1,50) = 6.17$, $p < .05$). Analyses of simple main effects revealed that within the more time pressure condition there was a significant difference between the time participants spent on first visits to easy and hard texts ($F(1,50) = 4.52$, $p < 0.05$), with more time being spent on the easy texts. This supports the hypothesis that more time pressure leads to more preference for easier texts. With the less time pressure condition, however, there was no significant difference between the time spent on the easy and hard texts ($F(1,50) = 1.96$, $p = .17$). This suggests that with less time pressure, participants do not have a preference for either the easy or the hard texts.

This finding, that more time was spent on the easy texts in the more time pressure condition, is consistent with the prediction that time pressure leads to more time spent reading easier items than when the reader is not under as much time pressure. It is compelling that this phenomenon is replicated despite a doubling in the number of available texts from 4 to 8.

2.2.6 Learning scores

Learning scores are not particularly germane to the main goal of this article. Scores on the post essay and post test were significantly higher than on the pretest, there were no other differences. This is somewhat surprising as it indicates that participants under time pressure did no worse than those who were given substantially longer on either the essay or the post test. It may also imply that the test of learning was not a completely valid test of the learning that could be achieved. However, we must note that this null result is completely irrelevant to our contention that participants' preferential allocation of attention is adaptive, given their learning goals; the null result is a comparison of the learning of participants in four groups, each of whom, we have argued, will have behaved so as to maximise their learning, given their task and constraints.

3. Experiment 2

Above we saw that people seem to adjust their browsing behaviour in terms of the amount of time they spend in easy or hard texts as a result of time allowed. As predicted when time is a scarce resource participants attempt to maximize their chances of obtaining a good score on the tests by spending comparatively longer in easier texts when compared to a situation where they have a larger time window. Increasing the time window essentially lowers the cost of accessing a text, it matters little if a text is explored and found to be unproductive, there is still plenty of time available (up to 45 minutes in the above experiment, but with a *minimum* reading time of 30 minutes).

Another question about adaptivity to local task demands is whether participants are sensitive to the the numerator of the hypothetical value/cost function, i.e., to the value of the information required? We investigated this by testing whether

participants informed that they were required to answer difficult questions would spend more time in harder texts compared to those who were informed that they would be answering easier questions. Having shown the same pattern of results and the same prevalence of the satisficing strategy when readers are allocating attention across either 4 texts or 8 texts, we omit this manipulation in the second experiment, in the interests of simplicity.

3.1 Method

3.1.1 Participants.

Twenty-four participants from Cardiff University were paid £5 to take part in this study, 12 per condition. Thirteen participants were female and eleven were male (mean age 21.6, range 18 – 35). Participants were screened to ensure that they had not participated in any of our previous experiments using these texts.

3.1.2 Design.

The study employed a between-participants design in a single variable, question difficulty, was manipulated (either read to answer easy or difficult questions). The menu order was counterbalanced between participants within each condition as before. The dependent variable was the time spent in each of the texts, of particular interest was the time spent reading the easiest text (see Results for justification). It was ensured that prior knowledge was balanced across the two conditions expertise being measured using the pre-test.

3.1.3 Materials.

The texts used were texts A, B, C & D as described above, originally used by Wolfe et al (1998) and subsequently by Reader & Payne (2007). The texts were prepared and accessed as described for Experiment 1. Text number was not manipulated in Experiment 2 as it was not relevant to the research questions.

As for Experiment 1, a pre-test questionnaire of 17 questions was used to determine all participants' background knowledge relating to the heart. This test was identical to the one used in Experiment 1 except that the questions were divided into two sections corresponding to their difficulty level. Difficulty level was established from performance on the test in Reader & Payne (2007), Experiment 1.

Categorization into easy and difficult was done by determining how many participants had answered each question correctly, and performing a median-split on these questions: those falling below the median being categorised as ‘easy’ those above as ‘difficult’. The two sections were clearly labelled ‘easy’ and ‘difficult’ to give participants an indication of what type of question to expect in the post-test.

An example of an easy question in the pre-test is: "How many types of blood vessels are there? Please name them." An example of a difficult question is: "The pacemaker is the common term for what specific part of the heart? Where is it located?"

Two sets of new, unseen questions, easy and difficult were generated and given to participants as a post-test, depending on the experimental condition. Each set contained four questions devised by the experimenters, who also judged the difficulty level. Easy questions concerned simple anatomical features of the heart and circulatory system; difficult questions concerned the initiation and regulation of the heart beat and mechanism of gaseous exchange. The questions were given to participants in the corresponding condition at the end of the session. These post-tests played no part in the hypotheses for this study and so were not analysed.

3.1.4 Procedure.

The procedure closely followed that for Experiment 1. At the beginning of the session, each participant filled in a personal details questionnaire, and then answered the pre-test questions. Once these were completed participants were informed that their goal was to read the information contained in the system in order to answer some new questions that were going to be either difficult or easy, depending on their experimental condition. They were informed that the new questions would be of similar difficulty to the difficult or easy ones in the pre-test.

As in Experiment 1, participants were given no information about the nature of the four texts other than their topic. They were informed how much information there was available (number of texts, number of computer “pages” and approximate length in A4 pages and number of words) and informed about the time limit. As before participants were advised that they were not necessarily required to read all of the texts, and not to take notes while reading.

When participants were clear what was expected of them, they were informed as to whether they would be answering easy or more difficult questions in the post

test. They were then instructed to click a button that started the timer and the reading phase began. Once the time limit had elapsed, the text screens were hidden from the participant and could no longer be accessed.

Once the reading phase was over, participants completed the new test questions (different questions according to condition). There was no time limit to answering these questions. Finally, they were asked to answer the pre-test questions once more.

3.2 Results and discussion

3.2.1 *Pretest scores*

As in Experiment 1, in order to prevent any effects of expertise on browsing behaviour it is important that both conditions should be reasonably matched on the pretest. As previously, this was the case: pretest scores easy questions condition M = 11.1 (SD = 6.9), difficult questions condition M = 10.1 (SD = 6.7). A t-test revealed that there were no significant differences, t (22) = 0.36, p = .72.

3.2.2 Browsing behaviour

Using the same criteria as in Experiment 1, Table 6 shows the breakdown of browsing strategy for each condition.

	Condition	
Strategy	Easy Questions	Difficult Questions
Satisficing	9	5
Sampling	3	6

Table 6: Breakdown of Browsing Strategy for each condition, Easy Questions and Difficult Questions. (Note: one individual was categorised in the residual category in the difficult question condition).

The overall percentage of samplers (41.6%) is higher than in any previous experiment except Reader and Payne (2007) Experiment 2, where readers were provided with summaries. It is not clear why there are so many more samplers in this study than in Experiment 1 which had similar learning goals (to answer questions). It

is the case, however, that the larger number of samplers in this study overall is due to participants in the difficult question condition rather than those in the easy question condition. It might be tentatively advanced that having the goal to answer difficult questions instils a greater urgency in participants to find materials of the appropriate level. However there was no statistically reliable difference between the two conditions, χ^2 (1) = 1.6, p = 0.20.

3.2.3 Preference for easier versus harder texts

Table 7 shows the predicted interaction between question condition and time spent in the easiest and hardest texts, a 2 (question type) by 2 (text) mixed ANOVA showed the above interaction to be significant F (1, 22) = 5.48, p<.05. A simple main effects analysis revealed there was a difference between conditions for time on Text A (p<.05) but not for time on Text D (p=.26).

	Mean (SD) percentage time spent reading…	
	Easiest text (A)	Hardest text (D)
Easy questions	43.13 (21.12)	9.46 (14.61)
Difficult questions	21.25 (24.48)	19.31 (25.71)

Table 7 Mean percentage of time spent in easy or hard texts as a function of question difficulty.

It therefore seems that participants in this study are sensitive to the perceived difficulty of the task: people who are studying for more difficult questions shift preference towards more difficult texts relative to those studying for easier questions. N.B. one should not read the averaged data of Table 7 as suggesting that individual participants in the Difficult-questions condition were indifferent to text difficulty, just because when averaged over all participants the same fraction of time was spent on the easiest and most difficult texts. The allocation times from the 15 minute condition for Experiment 1 in Reader & Payne (2007; where the embedding task was to write a brief essay) were 36% for Text A and 13% for Text D. That these figures lie almost exactly mid-way between the respective times for the easy and difficult questions above suggests that the preferences of participants in both groups of the current

experiment have shifted relative to what they might have been given arguably neutral 'essay preparation' task.

3.2.4 Satisficers and first visits to texts only

The number of satisficers and their distribution across conditions in this experiment is too low to conduct an ANOVA on the satisficers and first visits only (easy condition had 9 satisficers and the difficult condition only 5). The mean time satisficers spent on their first visit of each text was as follows: easy condition: text A, 173.32; text D, 94.26; and difficult condition: text A, 110.80; text D, 143.09.

3.2.5 Learning Scores

As in Experiment 1, post-test scores (not including the new questions) were higher than pre-test scores for both groups, with no significant difference between groups, suggesting that the total amount learned was little affected by reading to answer easy or difficult questions. As before, this null result has no obvious implications for our experimental hypotheses.

4. General Discussion

The primary finding of the two experiments in this paper is that when readers are faced with multiple electronic texts, they are able to allocate their limited time preferentially to those texts which, a priori arguments show, are likely to be more valuable to them, given their available time and their study goals. We do not have evidence that this allocation is optimal, only that it is adaptive in that it shifts in predictable, rational ways. In particular, we have shown that this sensitivity goes beyond judgments of relevance. As in the earlier studies by Reader & Payne (2007), our participants were presented with multiple texts on the same topic – all of which were relevant, in the intuitive sense of enabling a reader's currently active goal. Reader & Payne showed that time-pressured readers were sensitive to the difficulty level of texts, in relation to their own level of background knowledge: more expert readers spent more of their limited time on more difficult texts. The new studies in this article have shown, beyond this, that readers judge the suitability of various difficulty levels according to their available time and according to the complexity of their study goals: readers choose to study more difficult texts when they have more

time to process those texts, and when the test questions for which they are studying are themselves more advanced. This is an important addition to the literature, in our view, because it adds considerable support to the contention that browsers adapt to the local information environment and the features of their embedding task. Indeed, the current studies show sensitivity to relatively subtle differences among relevant documents, and to particular and relatively subtle aspects of the embedding task.

We should comment briefly on the lack of significant differences between groups on measures of learning (Experiment 1). It is worth reiterating that these results are orthogonal to our contention that allocation of attention is adaptive and in no way challenge it. Indeed, one might argue that a tendency of participants in all experimental groups to adapt to their particular situation is likely to work against any significant difference between groups in the amount learned.

As well as providing evidence for such adaptive browsing, we have provided further insight into the strategies that support it. In particular, in both experiments, we have found evidence for what Reader and Payne (2007) called a 'satisficing' strategy. In satisficing, judgment of a text is integrated with learning from the text. Readers are assumed to monitor the quality of learning as they read, and to abandon a 'patch' of text – moving to the next patch – when quality drops below a threshold.

Duggan and Payne (2009; 2011) have recently shown that satisficing allows skim readers to allocate more time to the most important parts of a single document when skimming single expository texts under time pressure. There is now, therefore, considerable evidence that readers will use the satsificing strategy to read under time pressure in various contexts.

One of the most interesting aspects of satisficing as a text-judgment strategy for multiple texts is that it works without any explicit comparison between texts - indeed, we take its signature to be that the longest visit to any document is the first visit to that document. It is particularly impressive, then, that it allows sensible time allocation across texts, time allocation that is sensitive to difficulty levels of texts and study questions, and to the amount of time pressure.

Although both our experiments support the widespread use of satisficing, they also demonstrate that it is not the only strategy by which readers may adaptively allocate time. As in previous work, a minority strategy of sampling has been observed, whereby readers quickly judge the texts before settling to study a subset at more length. Reader and Payne (2007) found that sampling became a majority

strategy when learners were provided with a succinct summary of text contents. In Experiment 2 in this article, sampling became quite a popular (although still minority) strategy, when the learner's goals were to study for difficult test questions.

In considering the applied implications of this work for text design and website design, it is fruitful to place it in the context of recent work on "document triage" as noted in section 1.3. This work assumes - with reasonable support from surveys and from everyday intuition, that rapid judgement of documents is often undertaken as a precursor to reading them - or to rejecting them.

One possible rapprochement between our work and this assumption is that we are modelling and studying a later phase of a typical process – a phase in which only relevant documents are under consideration. The document triage research instead focuses on relatively coarse judgments of relevance, and consequently assumes that aspects of a document like headers and abstract are the major drivers of readers' inferences (e.g. Cool, Belkin & Kantor, 1993).

This argument raises an issue with our experiment, and with experiments in HCI research in general, the issue of ecological validity: to what extent does the task of our participants accurately model an important class of tasks in the real world. Of course, there are issues here: for example our participants used an experimental interface, not exactly like any commercial product. Further, our participants were presented with a rather small number of relevant documents, differing in difficulty level (although they did not know anything about the documents' properties until reading them). However, we would argue that none of these particulars undermine our main findings: that readers are capable of shifting preferences toward or away from more difficult documents depending on their task and available time and that they can do this without explicitly comparing the documents. It will be interesting to consider exactly what aspects of the situation are necessary to support this ability - but such generalisations would also be problematic from any real-world study, which similarly could only address one or a few tasks and situations.

Returning to document triage, several document display techniques have been explored that may improve triage. For example, in Buchanan and Owen's (2008) notions of semantic zooming, the title and headers are exaggerated in size to facilitate rapid scanning. We find such techniques interesting and promising and we agree that in many situations readers will separate a judgment of relevance. However, the burden of our work on the satisficing strategy is that separating judgment from reading is

NOT a universal of time-pressured reading. If, instead, in many situations readers would prefer to integrate judgment and reading by employing a satificing strategy, then document display techniques will need to be sensitive to this strategy.

To display documents so as to facilitate satisficing, current semantic zoom techniques do not seem appropriate. What is required is to allow readers to rapidly judge the suitability of patches of text while reading, and to enable them rapidly to move on to the next patch if they want so to do (because the current patch has fallen below threshold). This approach would emphasise writing style – so that sections or patches of text are representative of their embedding super-patches, and it would emphasise within- and between- document navigation, so that the costs of moving to the next independent patch are minimal.

To conclude: we do not regard our work as contradicting document triage, but rather as complementing it. We believe that our experiments have shown that readers are able to allocate time across and within documents adaptively according to their abilities and needs, and that they often prefer to do this by a satisficing strategy that integrates learning *from* the texts with learning *about* the texts, rather than parcelling these objectives into separate phases. Text display techniques that optimise rapid judgments of relevance may, in some situations, interfere with this preferred strategy. Further research is needed to provide browsing tools that are sensitive to important differences in context, and supportive of the various strategies readers will use to browse effectively.

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